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Renewal Plan: Efficient Strategy for Optimum Development in Mature Fields – A Success Story from Sanga-Sanga Assets, Indonesia

Andre Wijanarko, Bambang Ismanto, Robhy Permana (VICO Indonesia), Italo Pizzolante (ENI)

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Abstract

VICO Indonesia is the operator of the Sanga-Sanga Production Sharing Contract located onshore of the Mahakam delta, East Kalimantan, Indonesia since 1968. Over 40 years the PSC has produced 70% of the estimated original gas in place, supporting Bontang LNG plant. VICO has 7 producing fields, in a complex fluvial deltaic deposition with more than 2700 gas and oil reservoir, mixed of depletion and water drive mechanism reservoir. VICO production peaked at 1.5 BSCFD in 1995 then start to decline. Current production is in the range 385 MMSCFD of gas and 14500 BOPD of liquids from 400 active wells.

In a situation of 46% annual base decline, to fulfill domestic and LNG contractual commitments and to optimize reserve recovery, VICO generated and implemented an integrated and aggressive work program called “Renewal Plan”. This is an integrated approach between reservoir management and technology application; it provides a detail road map to onward development strategy.

The main elements of the plan are extensive development drilling activities (conventional drilling, grid base drilling, cluster well drilling), low permeability reservoir optimization (horizontal well, hydraulic fracturing, radial drilling), production optimization (deliquification technique, permanent coil tubing gas lift for monobore type) and facilities optimization (reducing abandonment pressure by additional compression installation, wellhead compressor, debottlenecking).

Technology application in drilling, completions, production and facilities optimization combine with synergy from multidisciplinary team have resulted in maintaining VICO production decline in the range of 5% (vs 46% base decline), allowing promoting and partially replacing the reserves at an attractive development cost, even after 40 years production life.

This paper will describe the successful implementation of renewal plan in VICO Indonesia, which proved to be an efficient example of better reservoir management for optimum development of mature assets.

Introduction

VICO Indonesia Sanga-Sanga Production Sharing Contract (PSC) acreage, is located onshore of the Mahakam Delta, East Kalimantan, Indonesia. This is located within the Kutai Basin; which is characterized by the Samarinda anticlinorium [1], with a series of highly prolific North-East and South-West trending anticline(s). Hydrocarbon accumulations are most often located within a series of Mid-Miocene upper-delta and delta-plain sandstone reservoir(s), and are principally characterised by four-way dip closure or two way structural/stratigraphic traps. The depositional environment consists of numerous complex fluvial-deltaic, channel/mouth-bar sands.

VICO field consist of more than 700 production layers with more than 3000 reservoirs, which can be characterized by three distinct type of sand, the lowermost layers is described by a thick-band of sands (Badak G,H sands; Nilam G sands; Semberah J sands; Mutiara I), containing large reserves, with fairly low production rates and low permeability (0.1 to 10 md) sandstones characterized by a classical depletion-drive mechanism. The middle layer (Badak D, E, F sands; Nilam F sands; Semberah I sands, Mutiara F sands) have medium-large reserve, medium permeability (10 to 200 md) sandstoine with mixture of depletion drive-water drive mechanism. Whereas the uppermost layers, consists of another band of sands (A, B ,C, D sands); containing more productive reservoirs (200 to 2,000 md); which are much smaller in size and are characterized by a very strong water-drive mechanism.

VICO Indonesia has been actively exploring and developing this PSC acreage since 1968. There are 7 producing fields **(Figure 1),** Badak, Nilam, Semberah, Mutiara, Beras, Pamaguan and Lampake which currently produce 385 MMSCFD of gas and 14500 BOPD of liquids from 420 active wells which have mixed wellbore completion (single, dual selective, monobore, dual monobore, horizontal). The surface facilities supporting the production are 4 main production centers, 12 gathering stations and more than 90 compressors (in plant & wellhead). The overviews of 7 producing fields are explained below:

- Badak field is VICO first discovery and a giant gas field consisting of more than 180 production layers with more than 600 reservoirs. Since start up in October 1976, total of 236 wells have been drilled (consist of 325 strings) and currently produce 70 MMSCFD of gas with 1200 BOPD from 113 active wells (consist of 162 strings).

- Nilam field is the second largest hydrocarbon discovery, within the Sanga-Sanga PSC, with over 16,000 feet of sediment deposition; and typically over a thousand feet of stacked gas-bearing sand units with more than 1,300 individual gas tanks located thus far. While Lampake field is located in the west of Nilam field. During Nilam & Lampake field development life more than 340 production wells have been drilled (consist of 450 strings). Over 170 of these well-bores (consist of 230 strings) currently deliver the production to the plant with 140 MMSCFD of gas with 3800 BOPD.

- Semberah field is located in the most northern of Sanga-Sanga PSC, consisting of more than 100 production layers with more than 300 reservoirs which have produced over 38 years. Compared to Badak and Nilam field, Semberah has smaller size of tanks/reservoir in average. Since 1974, total of 95 wells have been drilled (consist of 125 strings) and currently produce 25 MMSCFD of gas with 1700 BOPD from 59 active wells (consist of 78 strings).

- Mutiara, Beras & Pamaguan field is located in the southern of Kutai Basin, it is a long, linear, asymmetric thrust-fault-bounded anticline striking nort-norteast-south-southwest. Pamaguan was delivered the first productions since 1974, and then Mutiara was discovered in 1982, delivery of the production on October 1991 after the start-up of Mutiara Gas & Oil Plant. These fields have 120 production layers with more than 800 reservoirs, a lot of lenses reservoir, small tank size and spread over all the area. During development life more than 200 production wells have been drilled (consist of 230 strings) and currently produce 150 MMSCFD of gas with 8600 BOPD from 82 active wells (consist of 124 strings).

After 40 year of production, these fields have now reached a fairly mature stage of its life, where most of the penetrated reservoirs/tanks have been depleted from original pressure. Coupled with the condition of 46% annual base production decline, this condition has resulted in significant challenges in delivering a continuous economic and efficient field development strategy while maximizing field production.

Renewal Plan

The complexity of subsurface combined with surface facilities, and condition of 46% annual base production decline, the target to maintain production is very challenging. VICO carried out reserves reassessment study, an integrated approach between reservoir management, technology application and aggressive work program with synergy from multidisciplinary team. It provides a detail road map to onward development strategy, and this integrated approach is called “Renewal Plan” **(Figure 1)**.

These “Renewal Plan” elements consist of:

1. Securing base production by implement Realtime Wellhead Surveillance to monitor well behavior and pro-active well reactivation, routine downhole survey (Static/Flowing bottom hole pressure, Pressure Build Up, Production Logging)
2. Extensive and aggressive development drilling; covering conventional wells, grid based drilling methods and cluster wells.
3. Aggressive Rigless; promote additional rate and reserve from reservoir & wells review for idle wells/strings, under performed wells and by pass zone.
4. Low permeability exploitation; new technology application such as horizontal wells, hydraulic fracturing, radial drilling/jetting.
5. Deliquification; implement capillary string injection, plunger and velocity string installation for liquid loaded wells.
6. Oil Development ; a synergy from grid based drilling and artificial lift optimization (gas lift)
7. Facilities optimization; reducing abandonment pressure by adding more compressor installation of Very Low Pressure System (VLP) and installing wellhead compressor.

We will now describe main elements of “Renewal Plan” in VICO Indonesia, which proved to be an efficient example of better reservoir management for optimum development of mature assets.

Securing Base Production

Securing VICO base production is one of the key to achieve production target, maintaining the production of existing wells is become first priority. Well monitoring and surveillance are the main target to secure the base production, previously VICO wells are monitored by frequent production test and mostly utilize human surveillance. The well monitoring based on well production test in regular basis (14 days cycle), the problem raised when some of the critical/liquid loaded wells are cease to flow between testing period, without any chance to reactivate the well. Other problem is commingle flowline configuration, since the commingle-wells were tested in satellite, the rate of each well was distributed by proportional rate based on the latest test, consequently the production performance of each well cannot be measured accurately which might lead miss interpretation for well test analysis..

And automation real-time monitoring well surveillance of wellhead pressure and flowrate data on each well was impemented. This Real Time Wellhead Surveillace (RTWHS) transmit the data from wellsite to VICO server and stored in the database. Operator and production engineer could monitor the behavior of the well realtime and this system has proven minimize a well down-time, lead to aggressive well reactivation and ensuring the well able to flow in the proper pressure system.

The RTWHS system has allowed continuous real time monitoring of the wells performance and has fundamentally changed the way we manage reactivation of dead wells, cyclic wells, deliquification and the distribution of wells to the different pressure systems within VICO production facilities **(Figure 2)**. This RTWHS installation has become standard for new wells wellhead spool installation, current status 90% of VICO active wells are equipped with RTWHS.

Downhole surveillance were also performed to monitor wellbore condition and reservoir behavior, such as a static/flowing bottom hole pressure , pressure build up (PBU), production logging. These data acquisition are used to update the reservoir model, well behavior which lead to wellwork/new wells development program for under-performed wells and reservoirs.

Aggressive Drilling Plan

This aggressive drilling plan was driven by the result of an integrated multidisclipinary team of geologist, reservoir & production engeneer, drilling & completion engineer and commercial. The review concludes the VICO remaining potential reserves is high, eventhough it has produced 70% over 40 years. The review generates a lot of potential remaining reserve which can be produced with a cost efficient and very attractive economics with current oil/gas price. The new wells development are covered conventional wells, grid based drilling and cluster drilling methods.

Conventional Wells

The development drilling concepts with conventional wells are implemented all over 7 fields, with the target:

a) Sparse area in the crestal structure which have potential higher position compared to existing wells that risked to ceased to water movement.
b) Deeper reservoir and sparse area in the flank area to explore the opportunity developing target zone which have limited well data.
c) Twin well, to recover the reserve from existing wells due to mechanical problem, plug abandon, and by passed reservoir which couldn't be accessed with offset wells.

One of the results is the successful result developing deeper zone in Nilam field, G-61.02 reservoir (~13,000 ft depth), by applying development to the west flank and sparse area, 25 MMSCFD gas productions was regained from this tank in 2009. Another good result is shown from the development drilling in deeper Badak reservoir (H Zones ; 12000 ft depth) **(Figure 3)**. This result leads to additional development wells opportunity to maximize reservoir recovery in the future.

Grid Based Drilling

Grid based drilling concept is semi statistical drilling targeting known reservoir and expected new pools in Mutiara, Beras and Pamaguan especially in the sparse area. Based on evaluation from historical drilling result in these fields, it is shown in drilling result, there are always new pools penetrated by new wells.

Overall, during 2007-2011 new pools incremental reserve contributes ~40% of the total incremental from Mutiara-Pamaguan new wells drilling. This grid based has increased Mutiara production from 100 MMSCFD to 125 MMSCFD whereas oil production has doubled as well from 4000 BOPD to 8000 BOPD.

Statistical model from post well review, showing the relation between incremental reserves from grid based drilling model and distance of well spacing (**Figure 4**). It is shown, less distance of well spacing; less incremental reserve could be gained, but eventhough current well spacing only 200-300 ft, the average incremental gain is about 1 BCF of gas which economically attractive for Mutiara-Pamaguan development. Statistically, future grid base drilling with low spacing distances, still have a great potential to get new pool as an additional reserves.

Cluster Drilling Concept

This cluster drilling concept is combination cost efficiency and development strategy for multi layered reservoir especially in Nilam and Badak Field. Well cost reductions are being achived through improved rig utilization and drilling multiple wells from single pad location, 2-3 wells within the same pad. This approach is very efficient for wells which located in the dense population area which risked to have longer time for purchasing land (higher cost) and building the location construction. Utilizing skidding rigs in this cluster of wells also reducing rig moving time significantly, from normal 14 days rig moving time become 2 days by skidding from one well to the other well.. Having cluster drilling also provide better reservoir management and optimize perforation strategy from penetrated reservoir which have various pressure, remaining reserve and deliverability. With the example of 3 wells in one cluster, the 1st well can be dedicated to deplete deeper reservoir which mostly have low rate, longer life time, and the 2nd well is optimized to produce high deliverability reservoir, while the 3rd well is dedicated for technology application i.e hydraulic fracturing to maximize the reserve recovery **(Figure 4**).

To support those drilling strategies, the reservoir management challenge is to optimize the well completion in order to have good commercial rate and to optimize reserve recovery from even marginal reservoir, this resulted in changing strategies of the well completion. Previous VICO completion design is utilize single/dual string 2-7/8", 2-3/8", 3-1/2"completion with multi packer installed for single/multiple perforation. This will lead a commingle production from several zones which reducing the maximimum potential of each individual zone. Single 4-1/2" monobore was became a solution to have better reservoir management, single production tubing and cemented the annulus area up to surface. Downside of 4-1/2" monobore completion are less flexibility to catch up deliverability target, since bottom up strategy concept is to maximizing recovery from lower perforation zone while several zone with potential high deliverability above are waiting and liquid loading issue, larger diameter create higher liquid loading rate, which potentially reduce the life time of produced zone.

A Dual 3-1/2” Monobore completion was implemented, flexibility of production strategy is achieved by utilize long string for maximizing reserve recovery and short string for optimizing production. Compare to previous completions, this dual 3-1/2” Monobore benefit are:

- Reducing completion cost by packer-less completion, not require rig for well intervention.
- Flexibility on production strategy to allow de-commingling zone
- Liquid loading issue on 4-1/2” monobore completion

This dual 3-1/2” Monobore become a standard completion for development drilling wells in all field of VICO Indonesia **(Figure 5**).

VICO drills 45 development wells per year in average, 250 wells were drilled from 2007- mid 2012 with attractive development unit cost . The aggressive drilling program has sustained VICO production decline, and 70% of gas and oil production today is from drilling result in the last 5 year **(Figure 6, 7)**.

Aggressive Rigless

While maintaining base production, optimization of existing wells is the priority to meet production target. A routine reservoir and well review were conducted to grow the hopper for wellwork intervention. In a routine basis, group of integrated team (geologist, production and reservoir engineer, petrophisics) evaluate the potential wells in order to promote more production and reserve in under-performed well, idle wells, by passed zone.

- Action to re-gain under performed wells and idle wells categorized as conventional wellwork
  For under performed well detailed review is performed to determine if these wells have sand problem, liquid loaded or there are other factors that cause a decline in production. Static / flowing bottomhole and production logging data are useful information for analyzing the problem, nodal analysis and material balance software were used to support the analysys. While for idle wells, detail review is performed to evaluate if the existing producing zone has produced ultimately, and review the remaining potential zones to be produce.
  The outcome wellwork program such as re-perforation, new zone perforation, unloading, water out zone isolation, sand screen installation are the solution.
- Bypassed Zone: A re-look of potential productive zones that were not interpreted as hydrocarbon zone in the past. The evidence of by pass coming from detail review based on log data, offset well production, mud-log data during drilling. The review of bypassed zone was performed initially in Badak wells , this bypass zone production delivered 30% of total Badak rigless production in the last 4 years, nowdays bypassed zone review has been extended to othe field to have more additional rate and reserve opportunities **(Figure 8**).

Low Permeability Exploitation

One of Renewal Plan target is re-gain the production and increase the reserve recovery from this low permeability zone. Since most of the fields have reached a mature stage, where the shallow and middle layers have been significantly produced and depleted, the remaining reserve are spread over in the deeper low permeability sand, which previous conventional low perm gas completion approachs have not been effective to deplete the reserve.

A comprehensive approach was identified and ranks the candidate reservoirs for low permeability development based on following criteria **(Table 1)**.

- Group I : The reservoirs in this group have multiple well penetrations, high recoverable reserves, better reservoir thickness; thus minimizing the geological uncertainty
- Group II : The reservoirs in this group are principally characterized as those with medium geological risk, proven productivity, slightly more less recoverable reserve than group 1.
- Group III : This group contains those reservoirs that have the highest reservoir uncertainty of all, higher geological risk, less incremental reserves compare to Group 1 & 2.

Several low permeability gas development strategies and technologies have been evaluated and executed since 2006. Those low permeability technology application covered horizontal wells, hydraulic fracturing, radial drilling/jetting.

Horizontal Wells

Horizontal well is one of solution to increase productivity in low permeability-gas; A horizontal well is a drilling method by having lateral section penetrated in the target reservoir.however there are numerous additional challenges in achieving effective horizontal drilling within deep, complex, fluvial deltaic environments. The strategy planned, was to drill and complete horizontal wells that would deliver sufficient rates over a significant period, in order to recover the reserves and replace 2 - 3 conventional vertical wells. The well candidate selection approach is based on a combination of the geological, reservoir evaluation and drilling considerations in mitigating risk, maximise recovery and costs efficient.

Since 2006, VICO has successfully drilled and completed 7 horizontal, these horizontal wells has proved the concept of low permeability development and regain the reserve form this low permeability reservoir. The initial gas production rate was significantly higher than conventional vertical well, which was producing from the same level of reservoir (**Figure 9**). Seven horizontal wells currently still producing, with total gas rate of 9.5 MMSCFD and cumulative production of 28 BCF **(Table 2)**. Horizontal well drilling has proven effectively produce the reserve in low permeability reservoir.

Hydraulic Fracturing

Hydraulic fracturing also a solution to enhance the low permeability production, this technology was targeted for low to medium reserve. Hydraulic fracturing is a stimulation attempt by pumping fluid into reservoir above fracture gradient to creates high conductivity communication with a large area of formation and bypasses any damage that may exist in the near-wellbore area.

VICO had performed more than 34 individual hydraulic fracturing treatments across the Nilam, Badak and Semberah fields during 1977-2002, but the fracture treatments generally resulted in severe under performance. Fracturing campaign success rates, where we have defined success as a well demonstrating any sustained increase in post-frac gas production vs. the pre-frac gas production, was as low as 15% of the number of wells treated.

Detailed and thorough review of the previous 30 Years of hydraulic fracturing operations within VICO and it was conclude there are some factors causing problems for hydraulic fracturing. Lessons learned were captured and resume the fracturing program with some improvements **(Table 3)**.

Between 2007-2011 total of 11 fracturing were performed, latest production contribution from all frac wells is 3.5 MMSCFD **(Table 4)** with cumulative production 6.3 BCF .. The improvement of frac candidate selection and frac job execution has increase frac success ration become 70 % of success ratio and continue the fracturing campaign to develop low permeability reservoir (**Figure 10**).

Radial Drilling/Jetting

Other technology application for low permeability development in VICO is radial drilling/jetting. Radial jetting is a technology to make lateral holes by hydraulicaly jetting into targeted reservoirs. The lateral hole is 0.5” in diameter with lateral length up to 100 m and can consists of 2-4 lateral directions in each depth of a reservoir. The 100-m of lateral holes is expected to increase drainage area of a well by lengthening producing interval and also to bypass damage zone by drilling mud in surrounding wellbore. A technology trial was performed to develop low permeability in Semberah field, the pilot well were executed in 2009 with no gain of production post radial drilling. Lesson learnt were captured and candidate selection and operational problem are the focus area for improvement for future application.

Deliquification

Large proportion of VICO’s existing wells production is subject to liquid loading leading to premature abandonment of producing zones and some wells has to be in cyclic production. This is influenced by tubing size, surface pressure and the amount of associated liquids being produced with the gas. Liquid loading of a gas well is the inability of produced gas to remove the produced liquids from the wellbore, leading to excessive back pressure on the production interval which reduces productivity.

Historically, VICO's approach to well reactivation / deliquification was the low cost low tech solutions such as venting, vycling, HP gas injection, soap stick with mixed success. In 2006, new technology trials are introduced, the installation of plunger lift and capillary string injection in liquid loaded wells were tested.

Plunger lift is one of the artificial lift methods to assist produced liquid from a gas well without additional energy. The idea is too keep the wellbore free of liquid by lifting the wellbore liquid with plunger intermittently to the surface **(Figure 11)**. Limited plunger lift installation candidates, due to previous VICO wells completion was developed to accommodate a multi layer zone production, and most of the old completion was single string or dual string with selective completion and the inside diameter is not entirely smooth due to a lot of completion jewelry. Smooth ID of tubing is required to allow plunger travelling up and down. Since 2006, only 8 active strings are equipped with plunger installation with total gas rate of 1 MMSCFD.

Capillary strings injection concept is introducing foaming agent into the wellbore through ¼" capillary string and inject the surfactant across the perforation, then the foaming agent is mixed with produced fluids, lightening the density of the liquid, increase the gas velocity and improve the ability of the well to produce liquids and stabilized gas flow (**Figure 11**). This capillary string chemical injection was chosen due to relatively simple application also can be applied to wide range of VICO's completion (monobore, dual string completion with nipple profile, selective completion produce through sliding sleeve.

Field wide capillary string injection installation were implemented since 2006, current status there are 65 capillary string injection installation, and successfully maintain the liquid loaded wells production with continuous flow (instead of cyclic mode) to deliver 16 MMSCFD **(Figure 14**).

Oil Development

The aggressive drilling program in Mutiara and Pamaguan area resulted in increasing of oil reservoir to be produced. Gas lift system is the preferred method for the artificial lift because VICO has a lot of gas resources. Since monobore wells has no annulus (cemented up to surface), there is no gas lift valve / side pocket mandrel available to introduce gas lift into production tubing.

A Solution for developing oil in monobore well completion is utilizing smaller inside diameter of coil tubing (normally use 1.5" diameter) into production tubing, which include special BHA (nozzle, dual flapper check valve, and nipple). Special tubing hanger attached to the top of the christmas tree to hold the inserted coil tubing. This application is known as "Permanent Coil Tubing Gas Lift" or PCTGL (**Figure 12**), which allows the gas lift injection into production tubing which was not originally completed with gas lift valve.

This method does not require the well to be re-completed with a rig, thus having a significant cost benefit and deliver the gain of oil production **(Table 5).** During 2010-2011, 16 unit of PCTGL were installed, successfully sustain 3500 BPD oil production.

Facility Optimization

Maximizing reserve recovery with the condition most of the production comes from depleted reservoir, several attempt to lowering abandonment pressure was implemented. The effort lowering flowing wellhead pressure of a well will keep the well flow above critical rate / liquid loaded rate for longer period of time. VICO have categorized four different pressure system for compression system:

1. High Pressure Compressor (HP) with inlet pressure of 700 psi and outlet pressure up to 1500 psi.
2. Medium Pressure Compressor (MP) with inlet pressure of 280 psi and outlet pressure up to 710 psi.
3. Low Pressure Compressor (LP) with inlet pressure of 100 psi and outlet pressure up to 320 psi.
4. Very Low Pressure Compressor (VLP) with inlet pressure of 25 psi and outlet pressure up to 120 psi.

Before 2006, only few of VLP Compressors are available, this condition resulted some of the wells were prematurely cease to flow due to inability to flow in lower pressure system. Several studies were performed to determine how lower field abandonment pressure; improve well productivity and reserves, better reservoir management for gas field natural decline. This study is resulted additional VLP compressors are needed, and to have other compressor with lower pressure than VLP system, called Extreme Low Pressure Compressor (Wellhead Compressor). Gas well which flow into VLP system (inlet 25 psig), have a typical of 50-60 psi flowing wellhead pressure, this situation allow potential reservoir abandonment pressure of 10% from original pressure. Having wellhead compressor installed in the wellsite, reduce the flowing wellhead pressure further more **(Figure 13**). These create an opportunity to have lower abandonment reservoir pressure become 6% from original pressure.

Current status up to 2012, most of the wells are flowing into VLP production system and some of them utilizing wellhead compressor. VICO has 30 units of VLP compressor with 310 MMSCF capacities and 30 units of wellhead compressors with 20 MMSCF capacities. Both VLP compressor and wellhead compressor become facility backbone delivering gas production from depleted reservoir.

Conclusion

The "Renewal Plan" provides a detail road map to onward development strategy and the implementation has proved to be an efficient example of better reservoir management for optimum development of mature assets. Technology application in drilling, completions, production and facilities optimization combine with synergy from multidisciplinary team have resulted in maintaining VICO production decline in the range of 5% (vs 46% base decline), allow promoting and partially replacing the reserves at an attractive development cost, even after 40 years production life **(Figure 14**).

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Nomenclature

BCF	Billion Cubic Feet
BHA	Bottom Hole Assembly
BOPD	Barrel oil per day
CT	Coil Tubing
FGS	Flowing Gradient Survey
FTHP	Flowing Tubing Head Pressure
MD	Measured Depth
MMSCFD	Million Standard Cubic Feet per Day
PBU	Pressure Build Up
PCTGL	Permanent Coil Tubing Gas Lift
POP	Put on Production
POOH	Pull Out of Hole
PSC	Production Sharing Contract
PSI	Pound per Square Inch
RIH	Run in Hole
RTWHS	Real Time Wellhead Surveillace
SGS	Static Gradient Survey
TCF	Trillion Cubic Feet
TVD	True Vertical Depth
VICO	Virginia Indonesia Company

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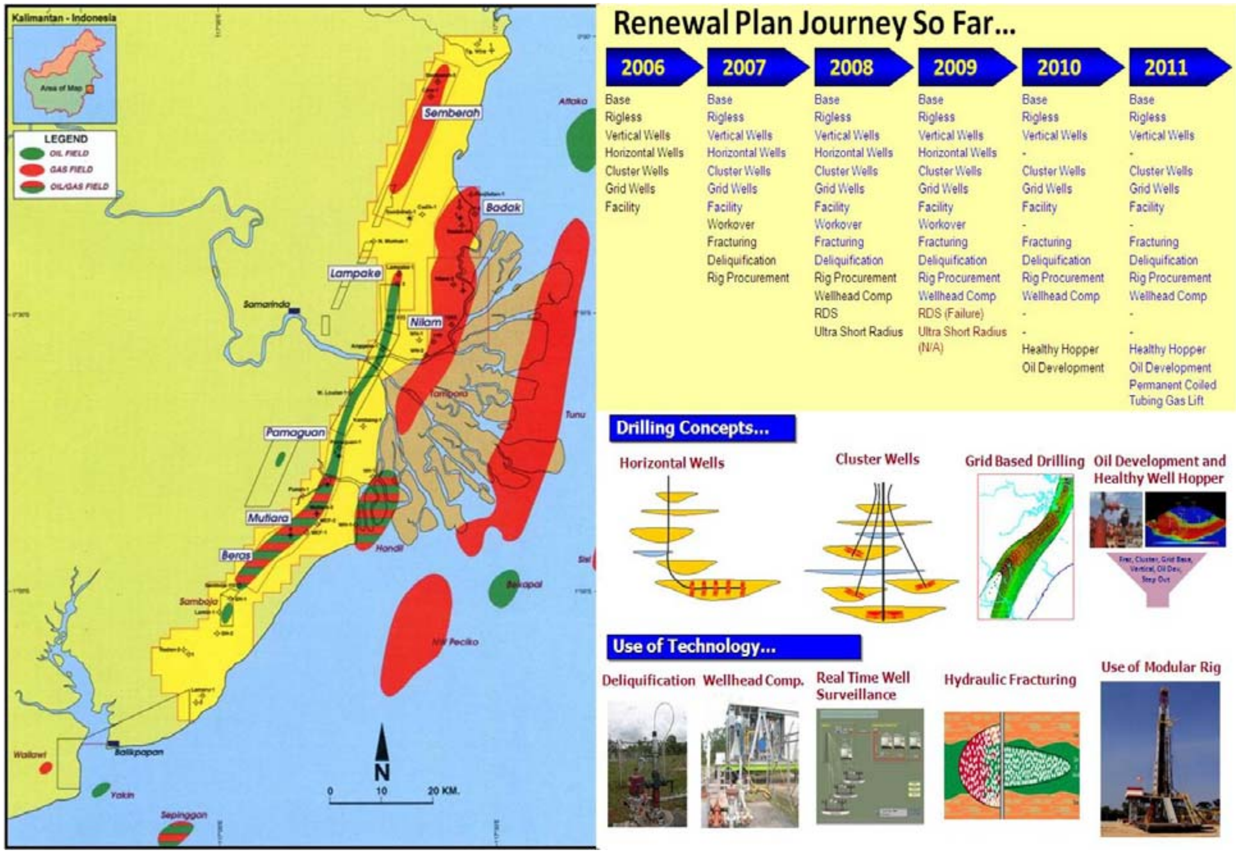

Figure 1. Sanga Sanga PSC and Renewal Plan Program

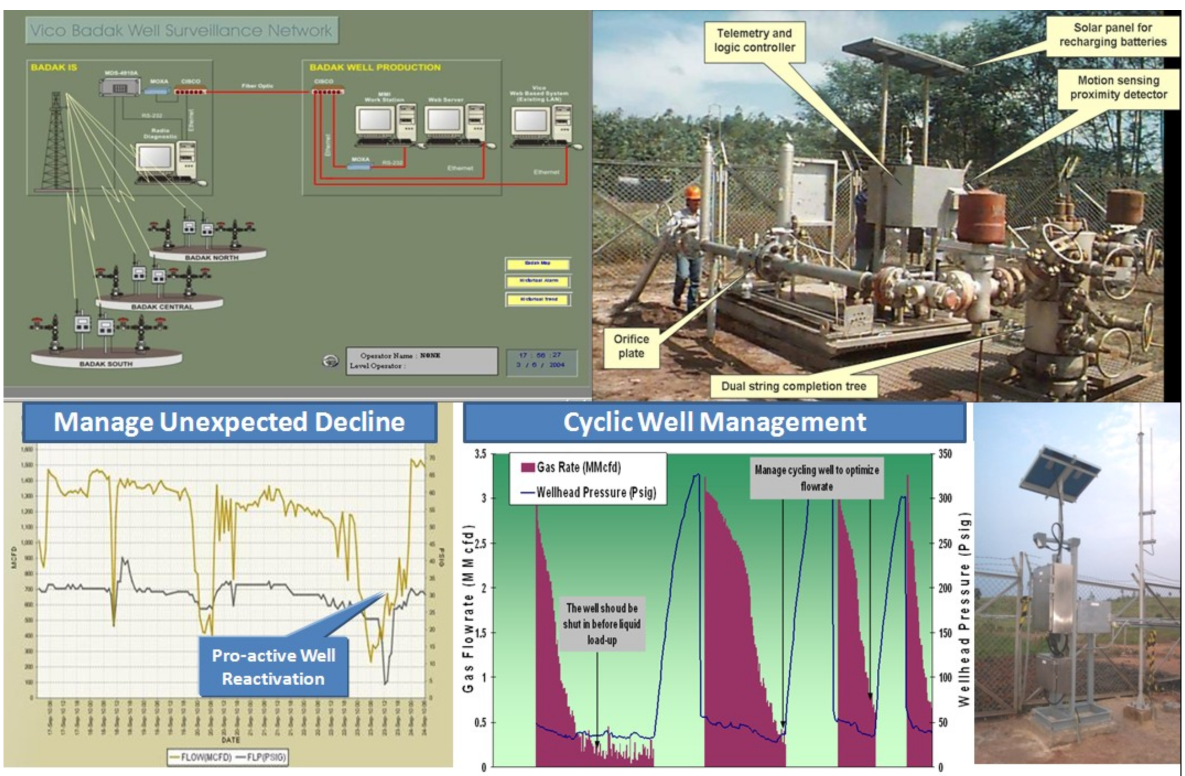

Figure 2. Real Time Wellhead Surveillance (RTWHS)

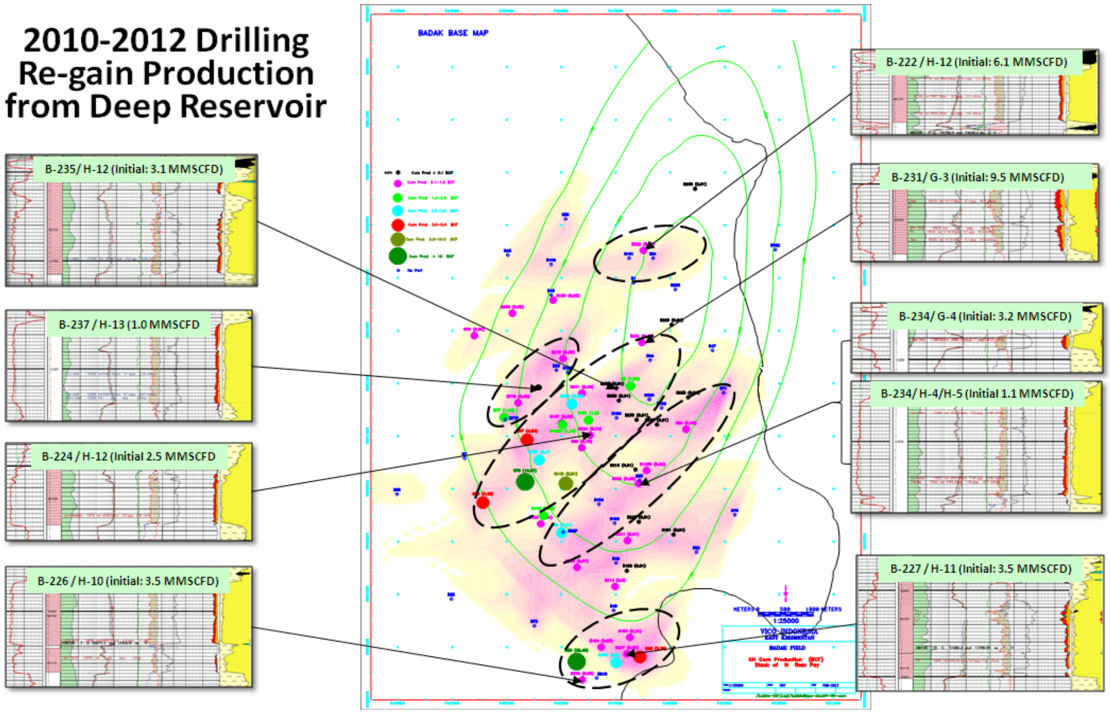

Figure 3. Conventional – Deeper Reservoir Result

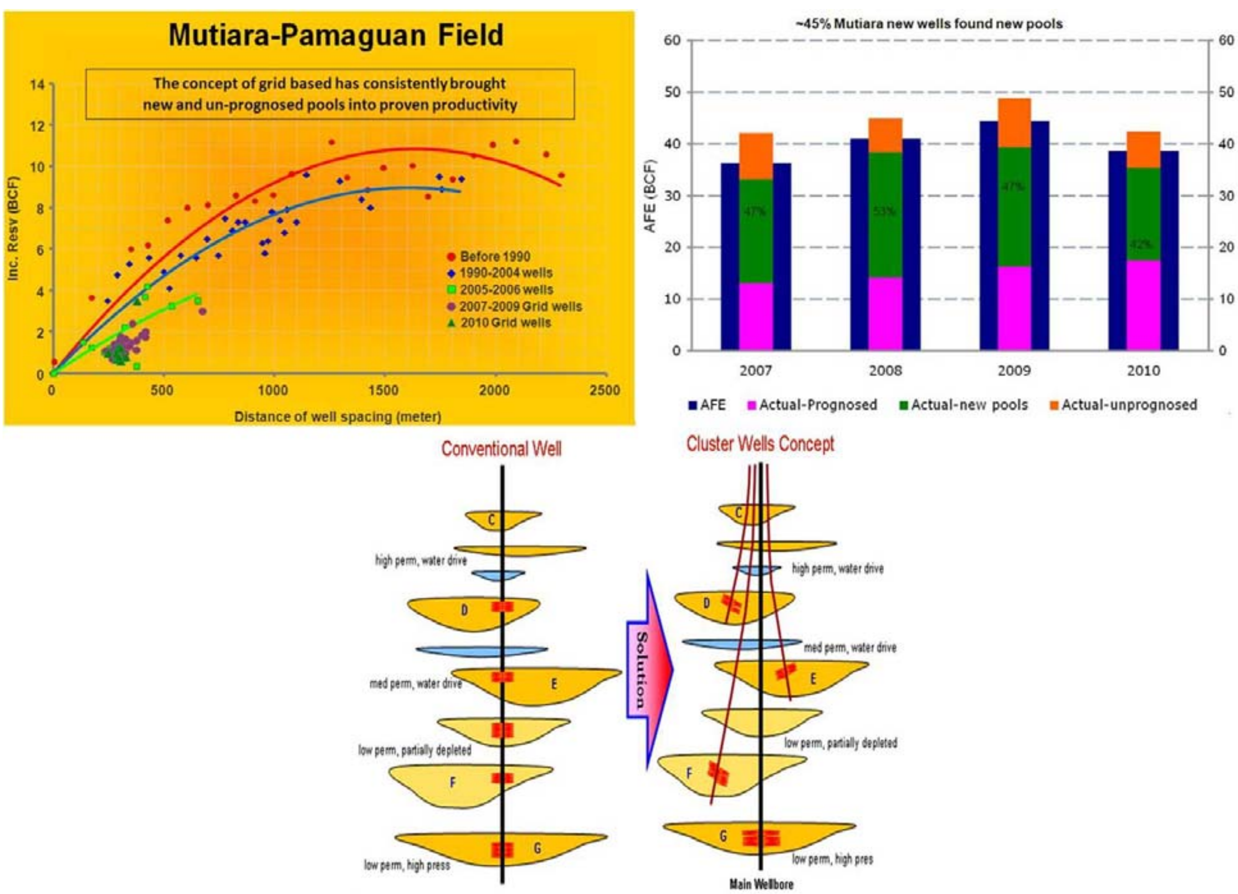

Figure 4. Grid Based and Cluster Wells Drilling Concept

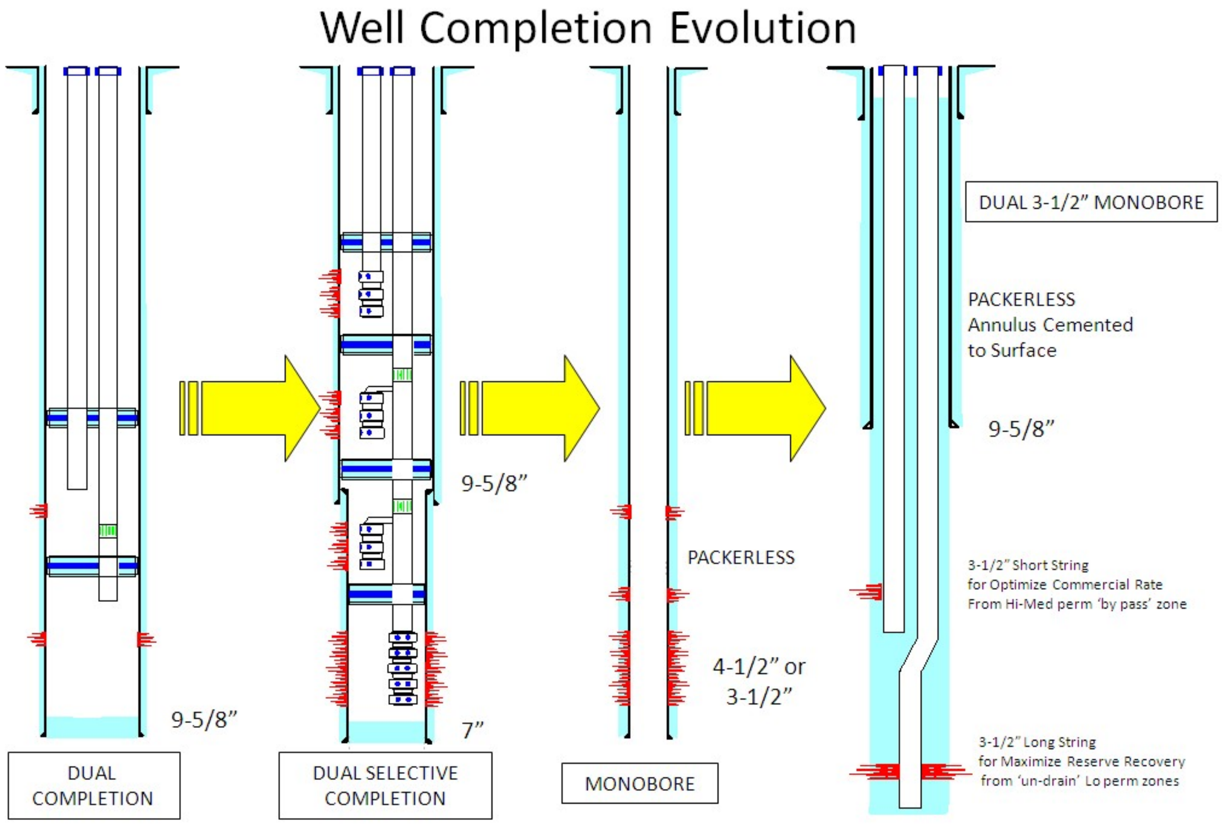

Figure 5. VICO Well Completion Evolution

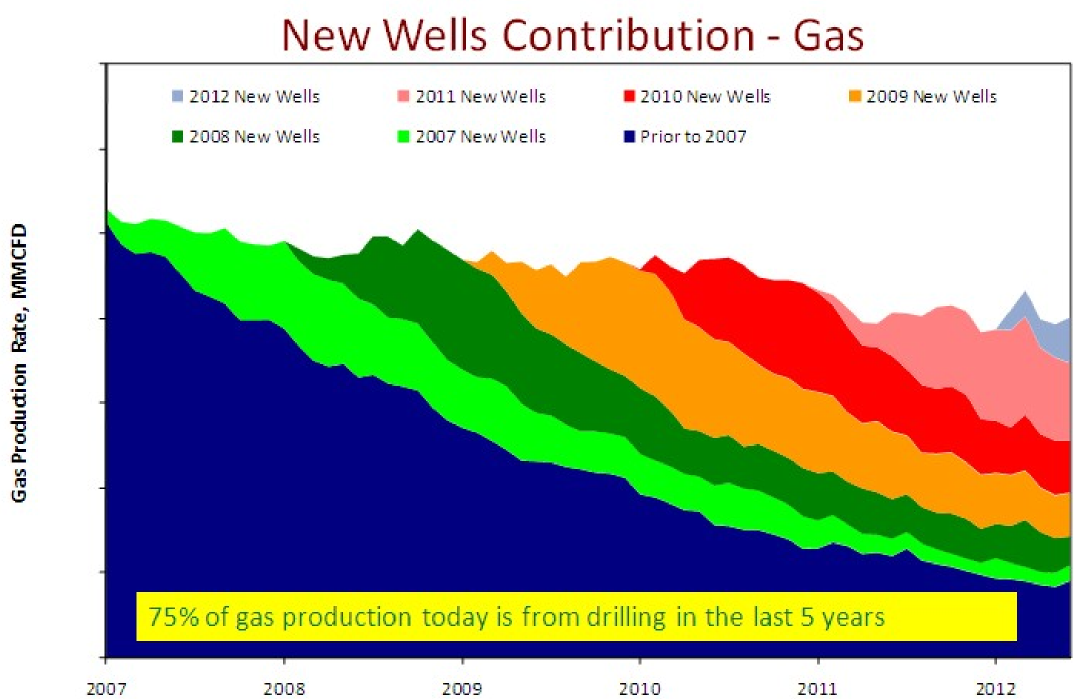

Figure 6. 2007-2012 New Wells Drilling Gas Contribution

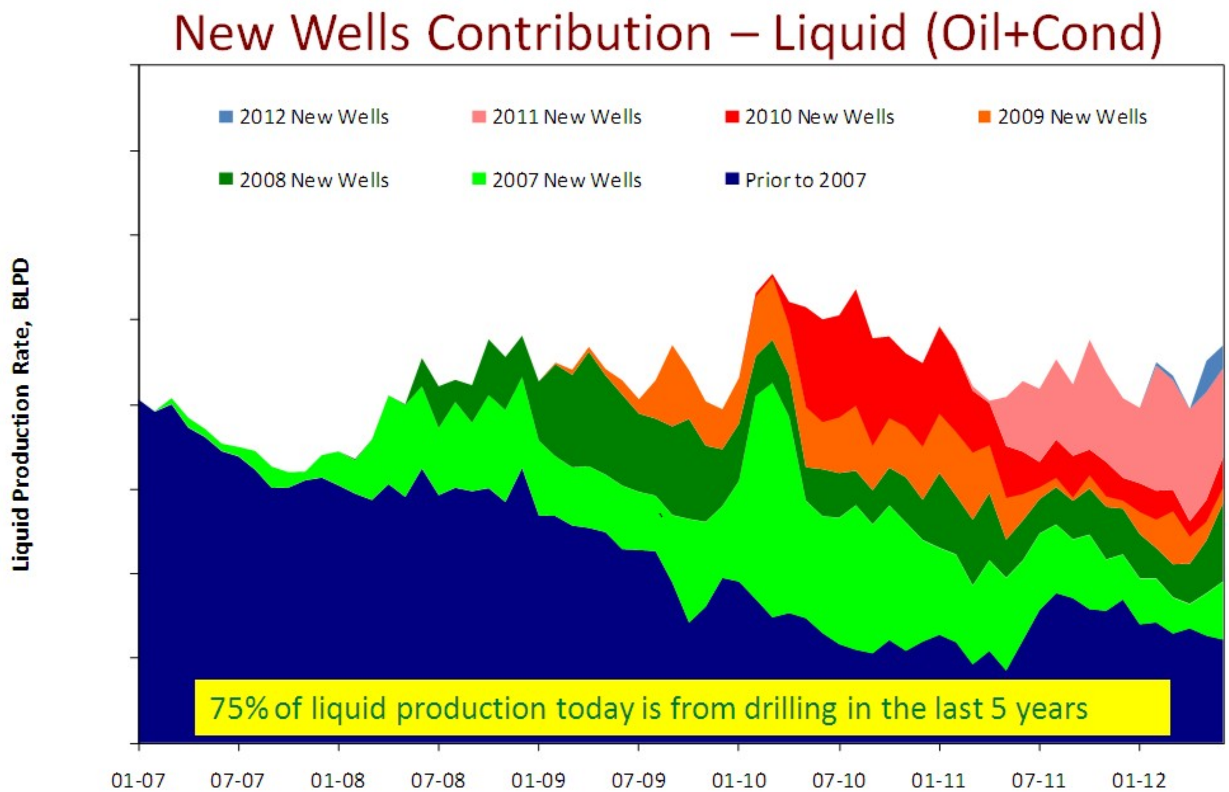

Figure 7. 2007-2012 New Wells Drilling Liquid Contribution

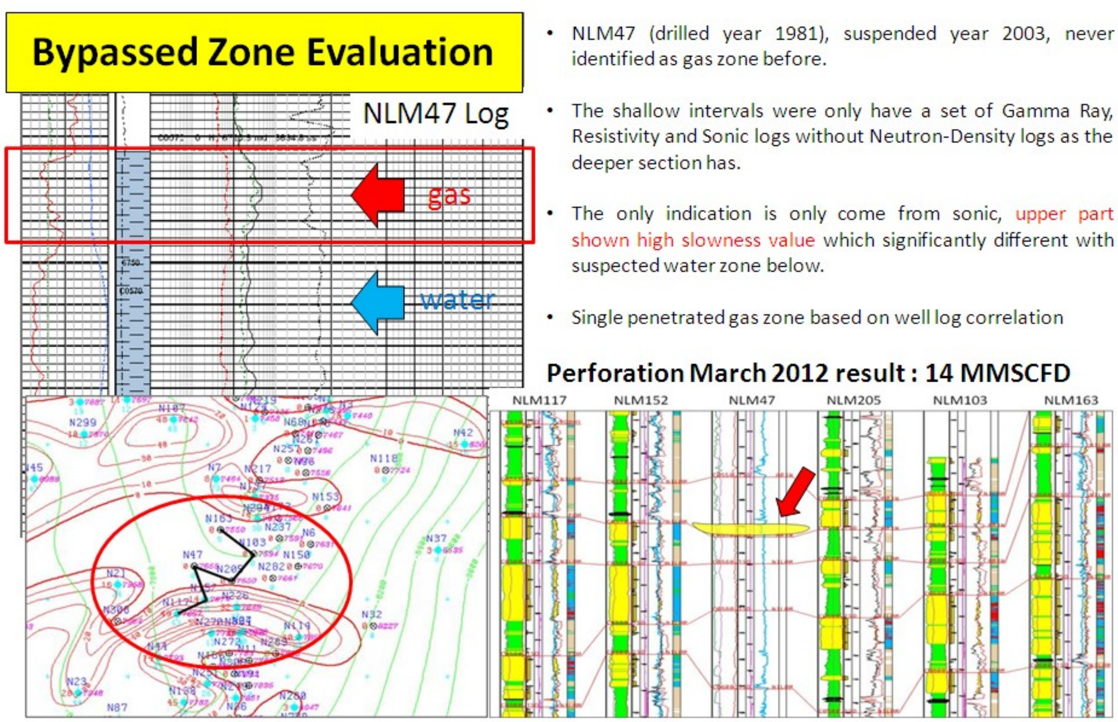

Figure 8. Aggressive Rigless –Bypassed Zone Example

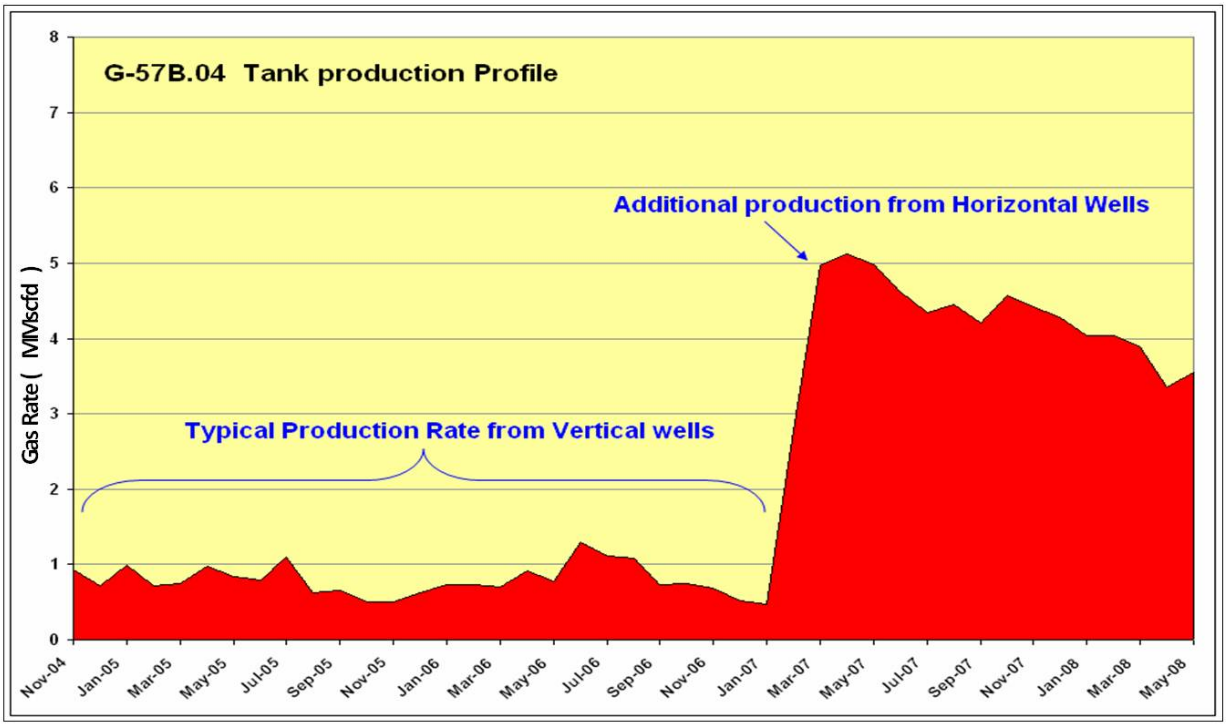

Figure 9. Low Permeabilty Productivity – Horizontal vs Vertical

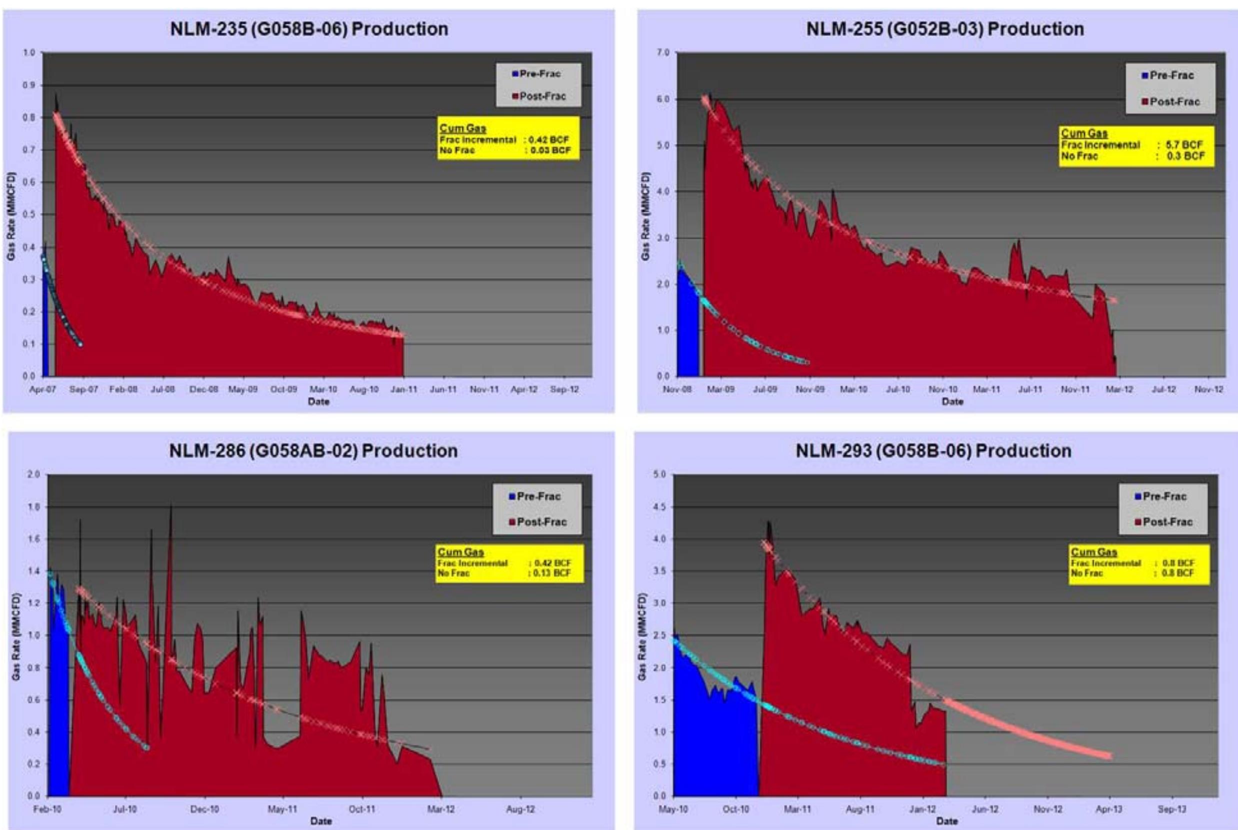

Figure 10. Case Example – Hydraulic Fracturing Pre Frac vs Post Frac Production

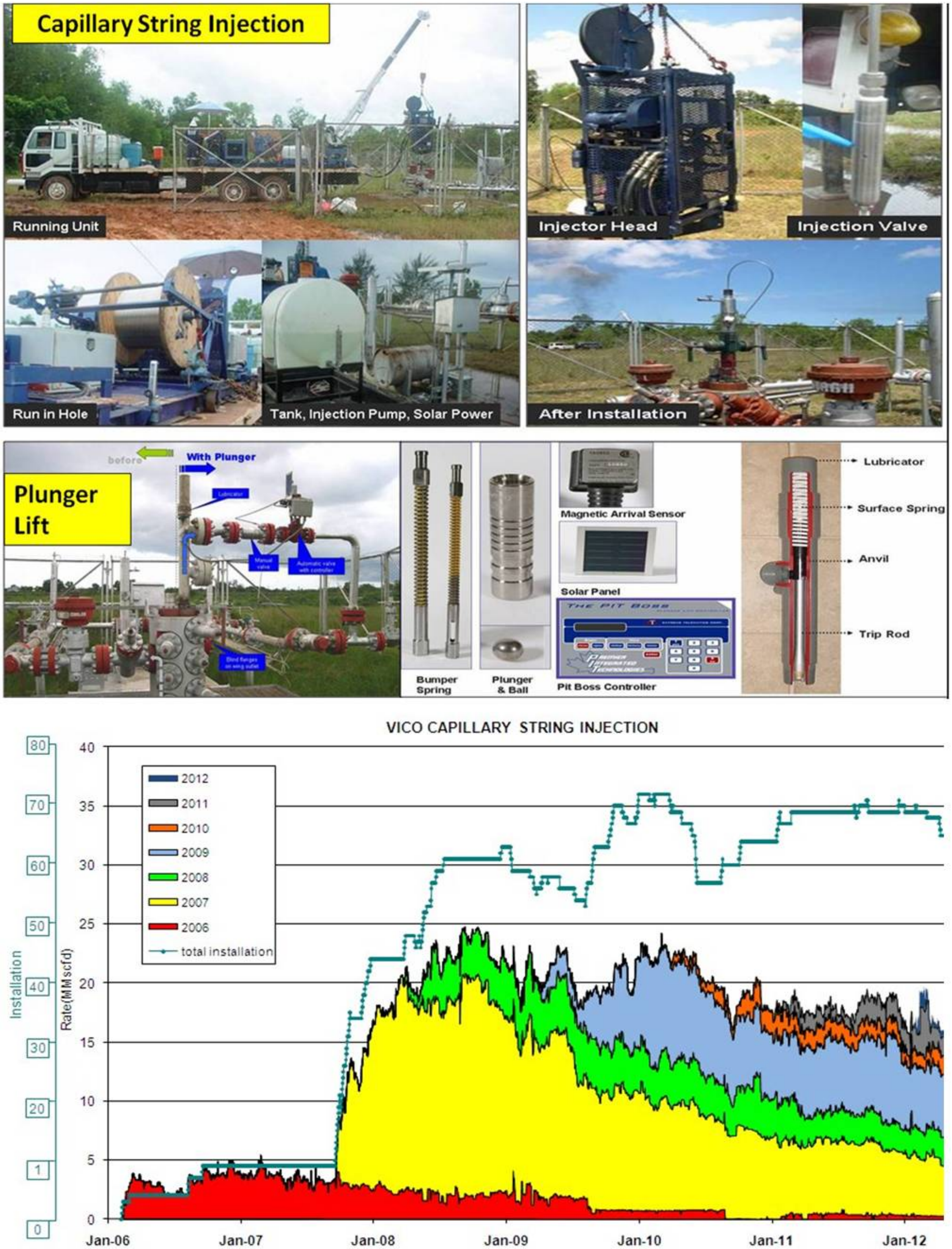

Figure 11. Capillary String Injection and Plunger Lift

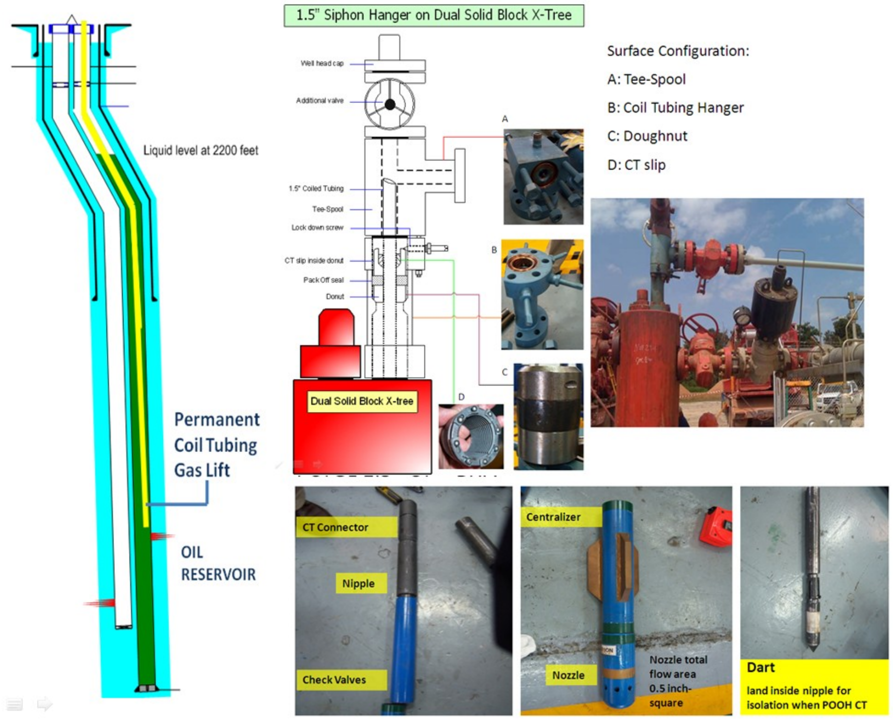

Figure 12. Permanent Coil Tubing Gas Lift

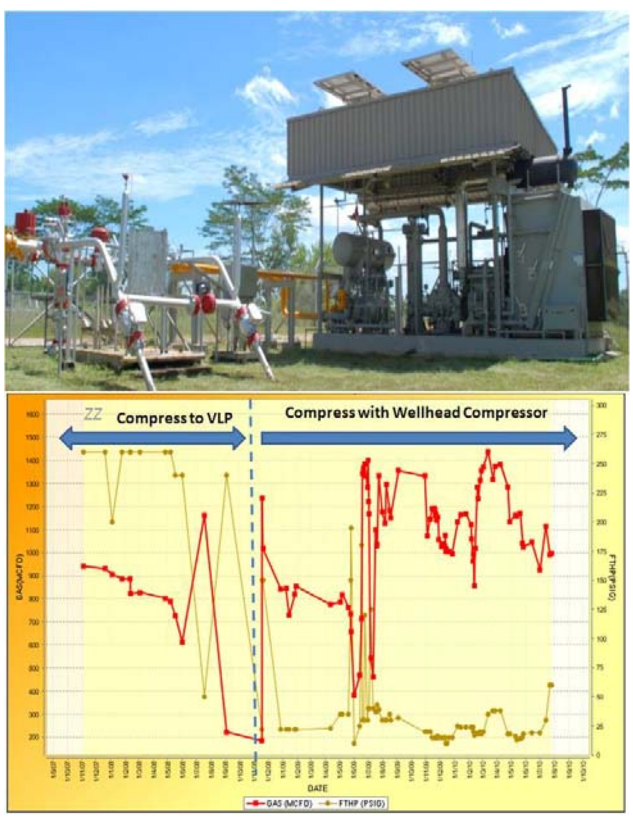

Figure 13. Wellhead Compressor

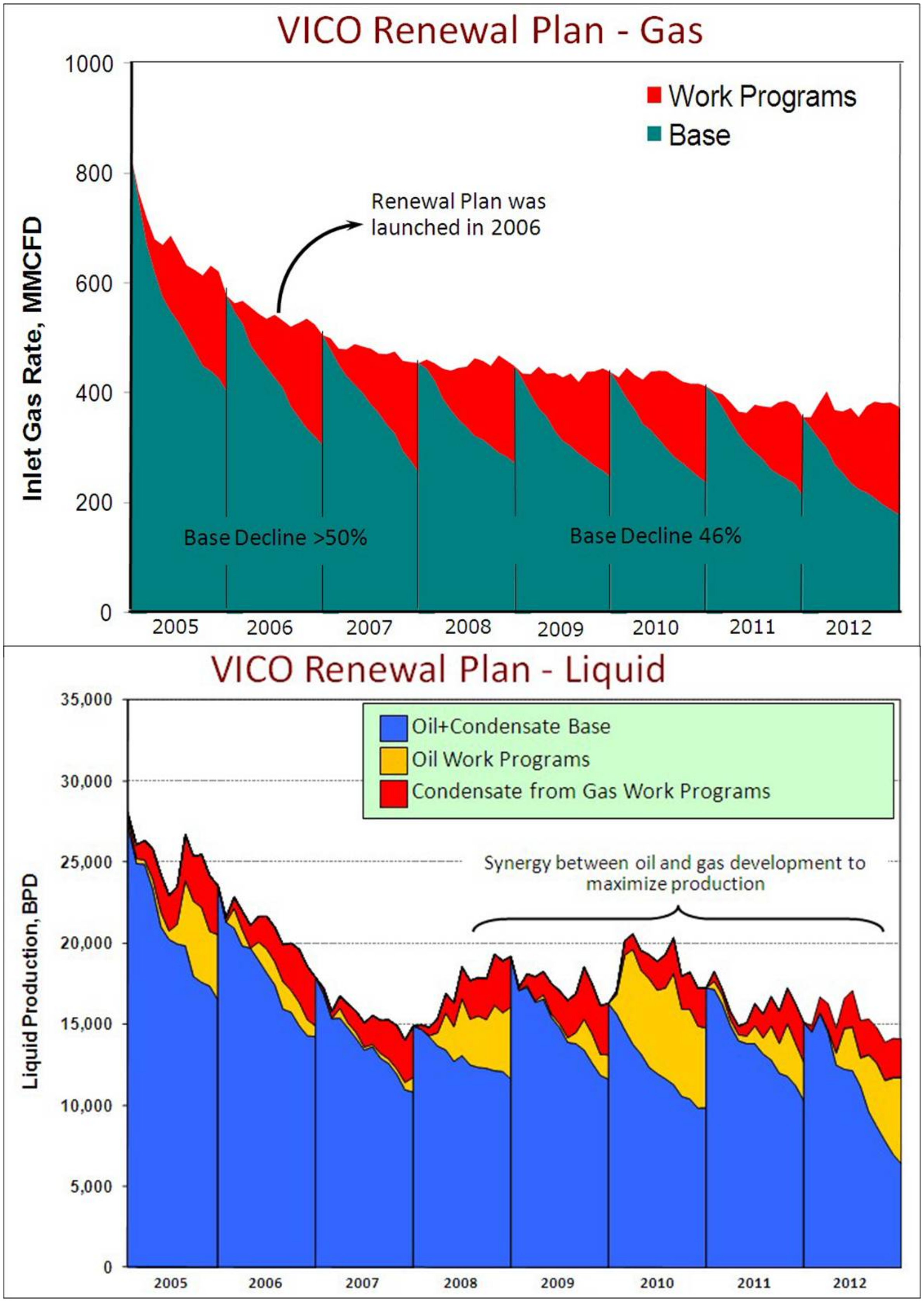

Figure 14. Renewal Plan Result - Gas and Liquid Production

Table 1. Low Permeability Development Criteria – Candidate Selection

Criteria	Group I	Group II	Group III
Geological Risk	Low	Low to Medium	Medium to High
Well Control	2 wells ; h > 50 ft	2 wells ; h > 20 ft	1 well ; h > 20 ft
Incremental Recovery	> 3 BCF	0.5-2 BCF	0.5 BCF
Reservoir Productivity	Proven Productivity	Proven Productivity	Proven / No Production data
Low Perm Technology	Horizontal , Fracturing	Fracturing, RDS, USRD	Other

Table 2. Horizontal Wells Result

		S-77H	N-228H	N-230H	N-238H	N-240H	N-260H	N-268H
Zone		J-70A.06	G-53A.03	G-57B.04	G-58B.02	G-52B.01	G-61.02	G-61.02
Pressure (psi)		3611	5100	2048	3700	800	1700	1200
HZ Length (ft)		865	500	1390	1764	624	1120	912
Rate (MMcfd)	Initial	13.6	6.1	6.0	6.1	4.6	8.5	9.6
	Latest (Jul 2012)	1.4	0.8	0.2	0.9	2.2	2.5	1.6
Cum (Bcf)	* as of Jul 2012	8.0	1.4	4.9	2.5	4.1	5.0	3.1
Completion	3-1/2"	Single	Single	Dual	Single	Single	Single	Single

Table 3. VICO Hydraulic Fracturing Improvement

	VICO FRACTURING	
	35 Fracturing Tratments 1979-2002	11 Fracturing Treatments 2007-2011
1. Well Mechanical Integrity	Liner 7" L80 29 Lb/Ft 8,160 psi burst rating Burst liner, Frac location largely unknown	4 ½" P110 23.5 Lb/Ft Burst 21,390 psi Max. allowable WHTP ca. 14,500 psi
2. Fracturing Material QA/QC	Poor proppant & basic water-based fluids Poor conductivity and formation damage	Appropriate Frac Materials, Fluids Testing, On-site QA/QC and Min. acceptance criteria
3. Fracturing Equipment	Regionally available equipment/personnel Poor pumping service/poor job quality	Appropriate Frac Equipment, yard-testing, Systems testing and suitability/operability
4. Rock (Reservoir Behaviour)	Severe rel-permeablity effects/water block Condensate banking/high decline rates	Application of micro-emulsion technology and tailored additives.
5. Rock (In-Situ Stress)	Frac gradients (closure) from 1.0 - 1.4 psi/ft Horizontal Fracs and Poro-Elastic effects	Fracture Gradients from 0.72 – 0.92 psi/ft Vertical Fractures (confirmed by Logs & PI)

Table 4. Hydraulic Fraturing Summary

FRAC SUMMARY		N-235	N-236	N-31S	N-237	N-255	N-262	N-286	N-278	N-31S	N-293	N-290
Completion		4-1/2 MB	4-1/2 MB	4-1/2 MB	4-1/2 MB	4-1/2 MB	4-1/2 MB	4-1/2 MB	4-1/2 MB	4-1/2 MB	4-1/2 MB	3-1/2 Dual
RESERVOIR	Zone	G-58B.06	G-58B.02	G-58B.04	G-54A.05	G-52B.03	G-57B.05	G-58A.04	G-61.02	G-57B.05	G-58B.04	G-57B.05
	Frac Date	May '07	July '07	Oct '07	Nov' 07	Jan '09	Mar '10	Apr '10	Apr'10	Nov'10	Dec '10	Dec '11
	Reservoir Pressure (psi)	2,503	3,481	2,130	3,700	1,700	3,671	2,125	1,344	3,800	2,810	2,168
	BHT (°F)	250	265	265	265	250	260	260	270	260	266	255
	Permeability (PBU)	0.3	1.2	1	N/A	5	1.8	0.6	4.6	1.6	2.2	1.3
	Porosity (%)	10	10	11	11	11	9	10	8	11	9	9
Result	Skin (Pre Frac - PBU)	3	28	6	N/A	13	6.2	-0.5	3.7	8.3	9.5	7.5
	Skin (Post Frac - Nodal)	-3	+2	N/A	N/A	-2	-2	-2	N/A	N/A	0	3
	Pre-Frac Production (MMCFD)	0.4	0.4	2.0	0.1	2.0	2.2	1.0	1.2	1.8	1.7	0.3
	Post-Frac Production (MMCFD)	0.9	2.2	0.0	0.0	6.0	4.4	1.2	0.0	0.0	4.2	0.4
	Fold Of Increase	2.25	5.50	0.00	0.00	3.00	2.00	1.20	0.00	0.00	2.47	1.33
	Latest Rate (MMCFD)	0.15	0.00	0.00	0.00	1.90	0.30	0.15	0.00	0.00	1.33	0.40
	Post Frac Cum Prod - Jul'12 (BCF)	0.45	1.26	0.00	0.00	3.10	0.90	0.36	0.00	0.00	0.56	0.00

* problem during Unload (CT parted and LIH)

Table 5. Permanent Coil tubing Gas Lift - Case Example

VICO PCTGL					
	NLM-X	MUT-X		NLM-X	MUT-X
Type	3.5 inch monobore			3.5 inch monobore	
Reservoir Properties			Coil Tubing Gas Lift		
Reservoir Pressure (psi)	2900	1041	Injection Depth (feet)	5600	1500
Zone Depth (feet)	9100	2652	Outer Diametre (inch)	1.5	1.5
Porosity (fraction)	0.21	0.28	Injection Pressure (psig)	1700	470
Permeability (md)	294	880	Rate - Before Installation (BOPD)	0	0
Water Cut (%)	88	60	Initial Rate - Post PCTGL(BOPD)	800	600
Average Skin Factor	8	10	FTHP (psi)	180	90